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Delving into Liberia's energy economy: Technical change, inter-factor and inter-fuel substitution

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ABSTRACT

The industrial energy mix of Liberia is dominated by petroleum products. This has generated serious environmental problems, contributing immensely to CO_2 emissions and other pollutants in the country. This study has attempted to investigate the potential for inter-factor and inter-fuel substitution between capital, labor, petroleum and electricity in Liberia by employing a translog production and cost function approach. Ridge regression procedure has been adopted to estimate the parameters of the function due to multicollinearity in the data. Estimation results show that all inputs are substitutes. These suggest that price-based policies, coupled with capital subsidy programs can be adopted to redirect technology use towards cleaner energy sources like electricity; hence, retaining the ability to fuel the economy, while also mitigating greenhouse gas (GHG) emissions. Substitution between energy and labor and energy and capital implies that removal of price ceilings on energy in Liberia would tend to reduce energy use and increase capital and labor intensiveness. Notwithstanding, the study seems to show no evidence of convergence in relative technological progress of the four inputs implying that petroleum will continue to play a dominant role in the energy consumption mix of Liberian industry while labor investment will continue to outweigh capital inputs. Finally, the findings of this study provide general insights and underscore the importance of policies that focus on installed capacity of renewable electricity, energy intensity targets as well as merger of enterprises.

Contents

1. Introduction

The energy sector is a driving force for nearly all socio-economic activities of Liberia as it propels industrial and commercial activities and enhances the delivery of basic social services. In fact, some of the key services that are inherently linked to the energy sector

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include transportation, electricity, communications, agriculture and fishery, health, education, and tourism. Besides its share to the overall gross domestic product (GDP) of Liberia as a sector, energy also contributes to employment, trade, fiscal revenues, food security, and regional and sub-regional development. The current energy economy of Liberia is dominated by petroleum products that are imported in refined forms, and woody traditional biomass consumed primarily for cooking and heating as in nearly all of Sub-Sahara African countries (see Wesseh and Zoumara [1])[1]. The patterns of energy use in Liberia, i.e. petroleum and electricity have been steadily increasing since the year 1991. As the economy grows, coupled with the recent discovery of oil, the use of these inputs is also expected to increase.[2] Petroleum is the most important fuel used in economic production. According to a UNDP 2010 study, the energy consumption mix of industry in 2008 was approximately 90% petroleum and 10% electricity. The dominance of petroleum in the energy mix has generated serious environmental problems, contributing immensely to CO_2 emissions and other pollutants in Liberia. As can be seen from Fig. 1, the amount of CO_2 emissions from the consumption of petroleum increased from 0.34 million metric tons in 1991 to 0.74 million metric tons in 2010 representing a total increase of 117.6%. Since 1991, emissions from the consumption of petroleum grew at an annual rate of 4.2%, making the control of CO_2 emissions of great urgency. Even though one may argue that Liberia's contribution to global warming is negligible on a global scale, chances are if climate change continues, the country is likely to be disproportionately affected by its impacts considering indicators experienced in the country.

Various interest groups have clamored for the use of cleaner and greener fuels and renewable energy sources. In Liberia, a broad range of policies have been introduced (albeit not fully implemented) to address some of these issues as well as to reduce the country's dependence on imported fossil fuels (see Table 1). Notwithstanding, the success of these initiatives will to a large extent depend on the degree of substitutability happening between different factors of production and fuel types. Indeed, the effects of output growth and changing fuel prices on the demand for energy depend on inter-fuel substitution and the substitutability of energy and other factors of production. These issues have attracted a great deal of attention in a large number of energy demand studies, with the majority of these studies focusing mainly on developed economies. Undertaking such a study for Liberia is necessary for several reasons. First, with increasing demand for classical factor and energy inputs as the economy grows and expands, forecasts need to be done so as to match this demand with the necessary supply. These forecasts should be based not only on the trend of total energy input consumption, but also on the degree of inter-fuel and inter-factor substitution happening across time. In other words, forecasts on future energy demand using demand models can be more reliable if the elasticities of substitution are taken into account. Second, the urgency to control CO_2 emissions in Liberia seems to suggest a need for the use of cleaner fuels. In fact, part of the objectives of Liberian public policies is to see that greenhouse gas emissions is reduced by 10% by the energy sector and to improve energy efficiency by 20% by 2015 (Wesseh and Zoumara [1]). This is a clear manifestation that if policy makers know which energy sources are highly substitutable, the information can be used to assess whether the promotion of the use of relatively cleaner energy sources as opposed to petroleum for instance would be successful. Third, the estimates could be used to construct energy-oriented computable general equilibrium (CGE) models for Liberia. The difference between normal CGE models and energy-oriented CGE models is that the latter introduces production functions through constant elasticity of substitution (CES) forms, where output is a CES combination of energy and non-energy inputs such that different energy forms may be substituted with one another. With energy and factor substitutions taken into account, the modeler can study the impacts of certain energy-related phenomena and policies (e.g. price hikes, price regulation, taxes and subsidies) on the economy. Finally and perhaps most importantly, inter-factor and inter-fuel elasticities of substitution have never been computed for Liberia. Hence, this study is expected to contribute in filling the literature gap for Liberia by estimating inter-factor and inter-fuel substitution elasticities through the use of a new and appropriate dataset and rigorous econometric methods. The rest of the paper proceeds as follows: Section 2 presents a brief review of existing studies. Section 3 gives a description of the dataset used in the study. Section 4 describes the model framework and estimation procedure. Section 5 presents the empirical results and discussion. Section 6 draws the conclusion and provides relevant policy suggestions.

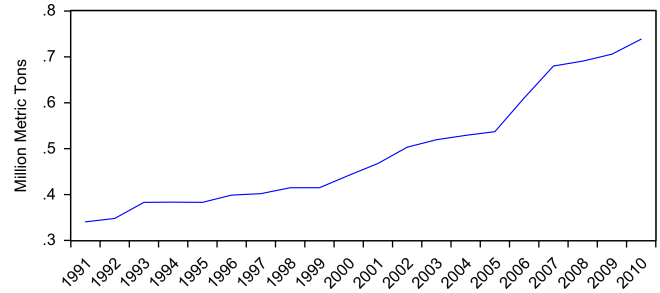

Fig. 1. CO_2 emissions from the consumption of petroleum (million metric tons). . *Source*: US EIA database [2]

2. A brief literature overview of existing studies

A considerable number of studies have employed various empirical methods to extract the elasticity of substitution among different inputs from data collected by researchers. Notwithstanding, the most popular method of estimating these elasticities in the field of energy economics studies has been the use of transcendental logarithmic (translog) cost functions due to flexibility of the specification, satisfaction of desired properties of production and cost functions, a tractable methodology, and the model itself being easy to understand. One of the first of these studies was conducted by Pindyck [4] on the estimation of interactor substitution elasticities across 10 developed countries. Pindyck's estimates show a positive elasticity of substitution between capital and energy; hence, these two inputs may be considered substitutes, a contradiction to what has been found in earlier studies (e.g. Halvorsen [5]). Also, labor and energy inputs were found to be substitutes in the study. Shankar and Pacauri [6] went further by analyzing not just inter-factor substitution, but also inter-fuel substitution possibilities in the context of India's industrial energy demand patterns. In general, the estimates of these parameters among different fuels were found to be low thus implying weak substitution or complementary possibilities among fuels, with oil and coal showing the highest degree of potential substitutability in several industries, particularly in the iron and steel industry. Electricity and coal were also found to be substitutable but to a lesser extent. Another significant result was derived from the estimates of the elasticity of substitution

[1] In Liberia, the market for woody biomass is informal. For this reason as well as the unavailability of data, this study does not consider traditional biomass energy.

[2] Wesseh and Zoumara [1] have shown that economic growth in Liberia depends on the level of energy consumption.

Table 1
Policies in place to promote the use of cleaner energy sources.
Source: IRENA [3]

Year	Policy
2006	Emergency Power Program; Liberia Emergency Assistance Program
2007	Renewable Energy and Energy Efficiency Policy and Action Plan of Liberia
2008	Action Plan for Renewable Energy and Rural Development
2009	National Energy Policy; Rural and Renewable Energy
2009	Division of Electricity and Renewable Energy Created within the Ministry of Lands, Mines and Energy
2010	Signing of the IRENA Statute; Liberia Energy Sector Support Program

between capital and energy. These two inputs were found to be complements, a result contradictory with the findings of Pindyck [4]. Other studies which have employed the translog cost function include but not limited to Hall [7] Considine [8]; Jones [9]; Bataille [10]; Soderholm [11]; Bousquet and Ladoux [12]; Nkomo and Goldstein [13]; Adeyemo et al. [14]; Penphanussak and Wongsapai [15]; Ma et al. [16]; [17]. There exist other methods which have been used to estimate inter-factor/inter-fuel elasticities of substitution (see e.g. Bjornerl and Jensen [18]; Chakir and Thomas [19]; Serletis and Shahmoradi [20]; Serletis and Timilsina [21]; Serletis et al. [22]; Smyth et al. [23]). Generally, the evidence on inter-factor/inter-fuel substitution from existing studies is mixed. To address the issue and uncover true values of elasticities as well as analyze the impact of the different factors on the elasticity estimates, Stern [24] conducted a comprehensive review of 47 studies of inter-factor/inter-fuel substitution across a number of countries and sectors. Differences in the estimates of inter-factor and inter-fuel elasticities of substitution were attributed to the methodology used, the country or economy of study, level of aggregation (e.g. national, regional, sectoral), data used (i.e. cross section, time series, pooled data), and sample size. Stern meta-analysis found that at the level of the industrial sector as a whole, coal–oil, oil–gas, oil–electricity and gas–electricity elasticities are significantly greater than one, while the coal–gas and coal–electricity elasticities are not statistically different from one. According to Smyth et al. [25], one problem with the literature is that many of the early contributions are dated because they use data prior to the 1970s, noting that in Stern's [24] meta-analysis, only one-third of the 47 studies used data after 1990. In fact, there are only few studies which have examined inter-factor/inter-fuel substitution in developing countries. As quoted in Smyth et al. [25], one such study is Serletis et al. [21], who examine inter-fuel substitution in six high income countries, five middle income countries and four low income countries. Serletis et al. [21] found that inter-fuel substitution possibilities between coal, oil, gas and electricity were consistently below unity. While these authors found some evidence of larger inter-fuel substitution potential in high income countries compared to middle-and-low income countries in the industrial and transport sectors, no such evidence was observed at the national level. Their general conclusion, consistent with Stern [24], was that inter-fuel substitution depends on the structure of the economy and not the level of economic development.

In light of the literature overview presented above, one can see that no attention has been paid to Liberia irrespective of the urgency major indicators have imposed. Undertaking a study of this nature is not only important for a country in transition like Liberia that suffers serious research vacuum but also very crucial for the energy policies of other West African countries especially in the context of ECOWAS[3] goal of a substantial reduction of greenhouse gas emissions and extending access to energy services for populations in rural and urban areas for poverty reduction in line with achieving the millennium development goals (MDGs).

[3] ECOWAS is the acronym for Economic Community of West African States comprising fifteen countries namely: Benin, Burkina Faso, Cape Verde, Ivory Coast, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo.

3. The dataset and its description

The chosen dataset includes yearly observations on output, gross capital formation, labor, petroleum consumption and consumption of electricity in Liberia over the period 1980–2010. In order to avoid spurious results of further inter-fuel and inter-factor elasticities of substitution analysis, several transformations of the dataset were performed. To eliminate the impact of inflation, we calculated output and capital stock at constant prices (2000 = 100). We also transformed each adjusted variable into logarithmic form, since this operation (as one of the Box–Cox transformations) may stabilize variances and therefore improve the statistical properties of the data, which is especially important for parametric tests. Data on output, gross capital formation and labor are from the World Development Indicators databank (WDI). Output in this study is represented by real GDP. Labor is calculated as employment to population ratio multiplied by the active population. Gross capital formation (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Inventories are stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales, and "work in progress". According to the 1993 system of national accounts, net acquisitions of valuables are also considered capital formation. Since WDI does not provide data of capital stock, this variable was calculated at constant prices (2000 = 100) using the perpetual inventory method given as follows:

$$K_t = K_{t-1}(1-\delta) + I_t \tag{1}$$

where K_t is the current capital stock, K_{t-1} is the capital stock of the previous year, δ is the capital depreciation rate, and I_t is the capital investment in the current year. The depreciation rate of capital is taken to be 5% which is based on the World Bank total wealth estimates and per capita wealth estimates for 124 countries including Liberia. We compute initial capital stock using the following equation:

$$K_0 = I_0/(g+\delta) \tag{2}$$

In the expression above, K_0 is the initial capital stock, I_0 is the initial capital investment, δ is the capital depreciation rate and g represents the average growth rate of capital investment over the period of study. Data on the consumption of petroleum and electricity are from US Energy Information Administration (EIA) database. All energy inputs are expressed in British Thermal Unit (BTU). A BTU is the amount of heat energy needed to raise the temperature of one pound of water by one degree F. This is the standard measurement used to state the amount of energy that a fuel has

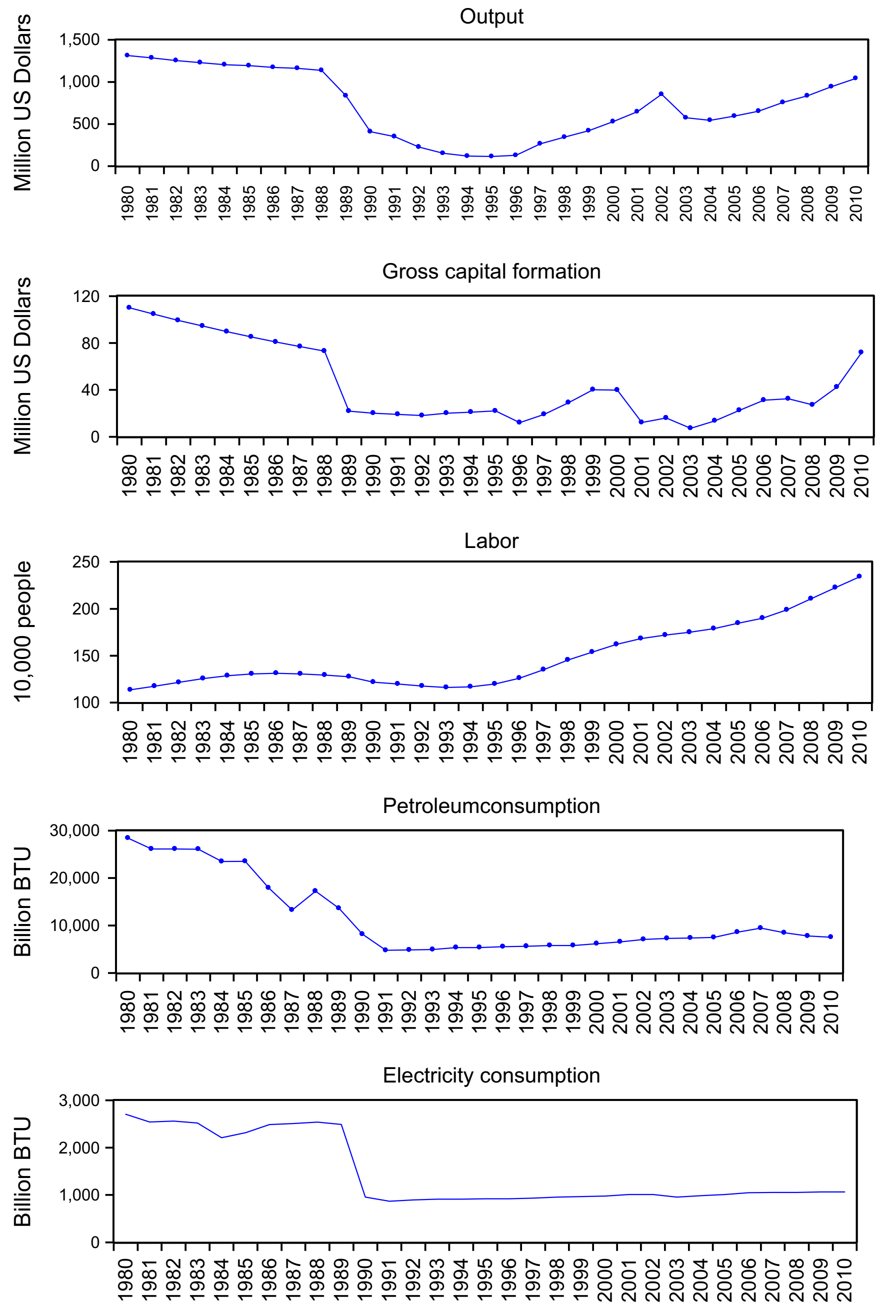

Fig. 2. Plot of variables 1980–2010.

as well as the amount of output of any heat generating device. Fig. 2 plots each of the variables over the period employed in the study. A cursory look at the plots seems to indicate likelihood of correlation among the independent variables thus suggesting the need to test for correlation among the predictor variables.

4. Model framework and estimation procedure

In this section, we present the methodology employed in our research and the procedure of extracting elasticities of substitution. As we've mentioned earlier, the most popular approach in the energy economics literature of estimating energy demand elasticities has been through the use of a translog cost function which requires data on input prices (e.g. wages, rent, and energy prices). Since most of these data are not available over our sample period, this study adopts the approach of Smyth et al. [25] by employing a log linear translog production and cost function to examine the extent of inter-factor and inter-fuel substitution between petroleum, electricity, labor, and capital in Liberia during the period 1980–2010.

4.1. Model framework

The translog production function which is a second order Taylor Series approximation describing the relationship between output and input services from several different productive factors can be expressed in a general functional form as follows:

$$\ln Y_t = \ln\alpha_0 + \sum_i \alpha_i \ln X_{it} + \frac{1}{2}\sum_i \sum_j \alpha_{ij} \ln X_{it} \ln X_{jt} \tag{3}$$

where Y_t denotes output at time t, α_0 signifies the state of technical knowledge, X_{it} and X_{jt} represent inputs i and j, respectively, at time

t, α_i and α_{ij} are technologically determined parameters. The basic assumption here is that for Liberia, there exists a twice differentiable aggregate translog production function relating gross output to capital, labor, petroleum, and electricity inputs. According to Pavelescu [26], the use of this functional form permits one to avoid the imposition of assumptions such as perfect competition or perfect substitution among inputs. The presence of quadratic terms also allows for nonlinear relationships between the output and the inputs. These characteristics make the translog production function attractive to researchers due to its flexibility relative to other functional forms. Given our energy inputs, the translog production function for Liberia can be specified as follows:

$$\begin{aligned}\ln Y_t &= \alpha_0 + \alpha_K \ln K_t + \alpha_L \ln L_t + \alpha_P \ln P_t + \alpha_E \ln E_t + \alpha_{KL} \ln K_t \ln L_t \\ &+ \alpha_{KP} \ln K_t \ln P_t + \alpha_{KE} \ln K_t \ln E_t + \alpha_{LP} \ln L_t \ln P_t + \alpha_{LE} \ln L_t \ln E_t \\ &+ \alpha_{PE} \ln P_t \ln E_t + \alpha_{KK} (\ln K_t)^2 + \alpha_{LL} (\ln L_t)^2 + \alpha_{PP} (\ln P_t)^2 + \alpha_{EE} (\ln E_t)^2\end{aligned} \tag{4}$$

In the above expression, Y_t represents output of the Liberian economy while K_t, L_t, P_t and E_t are inputs of capital, labor, petroleum and electricity, respectively; α is the input of the parameters to be estimated while t is a time index.

Characterizing the economic region of a linear homogeneous production function, the output elasticity (η_{it}) of the ith input from Eq. (3) can be computed as:

$$\eta_{it} = \frac{\partial \ln Y_t}{\partial \ln X_{it}} = \alpha_i + \sum_j \alpha_{ij} \ln X_{jt} > 0 \tag{5}$$

hence, the output elasticity for capital stock becomes:

$$\eta_{Kt} = \frac{d\ln Y_t}{d\ln K_t} = \alpha_K + \alpha_{KL} \ln L_t + \alpha_{KP} \ln P_t + \alpha_{KE} \ln E_t + 2\alpha_{KK} \ln K_t > 0 \tag{6}$$

The output elasticity for labor becomes:

$$\eta_{Lt} = \frac{d\ln Y_t}{d\ln L_t} = \alpha_L + \alpha_{LK} \ln K_t + \alpha_{LP} \ln P_t + \alpha_{LE} \ln E_t + 2\alpha_{LL} \ln L_t > 0 \tag{7}$$

The output elasticity for petroleum becomes:

$$\eta_{Pt} = \frac{d\ln Y_t}{d\ln P_t} = \alpha_P + \alpha_{PK} \ln K_t + \alpha_{PL} \ln L_t + \alpha_{PE} \ln E_t + 2\alpha_{PP} \ln P_t > 0 \tag{8}$$

The output elasticity for electricity becomes:

$$\eta_{E_t} = \frac{d\ln Y_t}{d\ln E_t} = \alpha_E + \alpha_{EK} \ln K_t + \alpha_{EL} \ln L_t + \alpha_{EP} \ln P_t + 2\alpha_{EE} \ln E_t > 0 \tag{9}$$

Indeed, the output elasticities are expected to vary across the sample since these are function of energy consumption per period. The elasticity of substitution between two energy or factor inputs can thus be calculated as:

$$\sigma_{ij} = \frac{\%\Delta(X_{it}/X_{jt})}{\%\Delta(P_{jt}/P_{it})} \tag{10}$$

Given the assumption that firms in the Liberian economy are cost minimizing agents, Eq. (10) can be written as:

$$\sigma_{ij} = \frac{\%\Delta(X_{it}/X_{jt})}{\%\Delta(MP_{jt}/MP_{it})} = \left(\frac{d(X_{it}/X_{jt})}{d(MP_{jt}/MP_{it})}\right)\left(\frac{(MP_{jt}/MP_{it})}{(X_{it}/X_{jt})}\right) \tag{11}$$

From Eq. (11), the final formula used for calculating the substitution elasticities between inputs i and j in this study becomes:[4]

$$\sigma_{ij} = \left[1 + \frac{-\alpha_{ij} + (\eta_i/\eta_j)\alpha_{jj}}{-\eta_i + \eta_j}\right]^{-1} \tag{12}$$

hence, the substitution elasticity between capital, labor, petroleum and electricity in Liberia can be written as:

$$\sigma_{KL} = \left[\frac{1 + -\alpha_{KL} + (\eta_K/\eta_L)\alpha_{LL}}{-\eta_K + \eta_L}\right]^{-1} \tag{13}$$

$$\sigma_{KP} = \left[1 + \frac{-\alpha_{KP} + (\eta_K/\eta_P)\alpha_{PP}}{-\eta_K + \eta_P}\right]^{-1} \tag{14}$$

$$\sigma_{KE} = \left[1 + \frac{-\alpha_{KE} + (\eta_K/\eta_E)\alpha_{EE}}{-\eta_K + \eta_E}\right]^{-1} \tag{15}$$

$$\sigma_{LP} = \left[1 + \frac{-\alpha_{LP} + (\eta_L/\eta_P)\alpha_{PP}}{-\eta_L + \eta_P}\right]^{-1} \tag{16}$$

$$\sigma_{LE} = \left[1 + \frac{-\alpha_{LE} + (\eta_L/\eta_E)\alpha_{EE}}{-\eta_L + \eta_E}\right]^{-1} \tag{17}$$

$$\sigma_{PE} = \left[1 + \frac{-\alpha_{PE} + (\eta_P/\eta_E)\alpha_{EE}}{-\eta_P + \eta_E}\right]^{-1} \tag{18}$$

In the above, σ_{KL}, σ_{KP}, σ_{KE} σ_{LP}, σ_{LE}, σ_{PE} indicate inter-factor/inter-fuel elasticities between capital–labor, capital–petroleum, capital–electricity, labor–petroleum, labor–electricity and petroleum–electricity, respectively.

4.2. Estimation procedure

Reflecting on the behavior of our data (see Fig. 2) and due to interaction and squared terms of the input variables in Eq. (4), likelihood exists for the model to suffer from severe multicollinearity—a statistical phenomenon in which two or more predictor variables in a multiple regression model are highly correlated. In this situation the coefficient estimates may change erratically in response to small changes in the model or the data. Given n inputs, the number of parameters that need to be estimated totalizes $n(n+3)/2$ if all inputs have translog components in the model. In fact, the number of parameters 'explodes' with the number of inputs included in the model leading to over parameterization. In fact, in the model framework proposed by Smyth et al. [25] the translog components for capital and labor and the substitution elasticities between these factors and energy inputs were not computed. This was done to lower the number of parameters to be estimated in the model and to focus only on inter-fuel elasticities of substitution. In order to properly handle any problem of multicollinearity, this study utilizes the ridge regression technique proposed by Hoerl and Kennard ([27,28]) for estimation.[5] The ridge estimator is obtained by solving $(X'X + kI)\hat{\beta} = h$ to give $\hat{\beta} = (X'X + kI)^{-1}h$; where $h = X'Y$, k is the ridge parameter or the biasing parameter which satisfies $k \geq 0$ and I is an identity matrix. In general, there is an optimum value of k for any problem. But it is desirable to examine the ridge solution for a range of admissible values of k. Small positive values of k improve the conditioning of the problem and reduce the variance of the estimates. While biased, the reduced variance of ridge estimates often result in a smaller mean square error when compared to least-squares estimates. Hoerl gave the name ridge regression to his procedure because of similarity of its mathematics to methods he used earlier, i.e. "ridge analysis", for graphically depicting the characteristics of second order response surface equations in many predictor variables. In the econometric literature, several methods of obtaining the optimal value of the ridge parameter have been proposed. This study uses the ridge trace plot method which is the most popular in the literature. Coefficients are estimated with

[4] For more details and full derivation of the substitution elasticity formula, interested readers are referred to Smyth et al. [25].

[5] The model is implemented using MATLAB programming language.

various levels of k from zero to one. The $\hat{\beta}_i$ coefficients are then plotted with respect to the values of k and the optimal value is chosen at the point where the $\hat{\beta}_i$ coefficients seem to stabilize.

5. Estimation results and discussion

In an attempt to pave the way for our empirical investigation, the Pearson's correlation coefficients[6] were computed for each of the predictor variables in the system. The coefficients measure the level of linear dependence between two variables giving a value between +1 and −1 inclusive. While this measure has been questioned by a couple of authors recently (e.g. Ahlgren et al. [29,30]) on grounds that the measure is sensitive to zeros, some authors (e.g. White [31]; Bensman [32]) have defended the use of the Pearson's correlation tests with pragmatic arguments that the differences resulting from the use of different similarity measures can be neglected in research practice. Moreover, unlike other techniques to correlation (e.g. the cosine of Salton and McGill [35]) Pearson's correlation coefficient is embedded in multivariate statistics, and because of the normalization implied, this measure allows for negative values. Results of the correlation analysis are presented in Table 2. As may be observed, except for labor and capital, the tests demonstrate evidence of strong and significant multicollinearity among the predictor variables. It is also interesting to note the negative correlation between labor and energy inputs. In general, these results suggest that the ridge regression procedure adopted in this study is a more appropriate econometric technique since coefficient estimates for multiple linear regression models rely heavily on the independence of the model terms. Based on the ridge trace plot presented in Fig. 3, this study adopts 0.6 as the ridge parameter since it is approximately at this value that the coefficients appear to have stabilized.[7] Results of the ridge regression run are shown in Table 3. One can easily see that all major parameters have the expected sign and all except one of the parameters are statistically significant. Judging from the coefficient of determination (R^2) and the F-statistics, nothing seems to be wrong with the model specification. The results from Table 3 are supportive of Wesseh and Zoumara [1] findings on energy consumption—economic growth nexus in Liberia and indicate that capital, labor, petroleum and electricity are positively and significantly linked to the output of the Liberian economy. Contrary to Wesseh and Zoumara [1] findings however, the level of employment seems to have a higher impact factor than all the other inputs.[8] This should not be very surprising since we have seen that over our sample period unlike other variables, the level of employment has exhibited a significant upward tendency[9]. This result should be interpreted with care however as it might not be sufficiently robust to support the inference that labor plays a significantly more important role in output of the Liberian economy. From the parameter estimates in Table 3, the output elasticity for each input was computed. These results are shown in Table 4. As can be noticed, positive output elasticities have been obtained for capital, labor, petroleum and electricity. This is indicative of the increasing trend in the use of these inputs over time as the output of the economy increases. Except for labor which was found to be elastic, the computed output elasticities were found to be inelastic and relatively stable over the sample period. The elasticity of labor highlights the degree of responsiveness in output of the Liberian economy for a unit change in labor and demonstrates the need for more efficient and effective labor policies. Based on the output elasticities in Table 4, elasticities of substitution for the various inputs were computed as given in Table 5. The results from Table 5 shows all elasticity estimates to be positive and very close to unity suggesting that all input pairs considered in the study are substitutes. The magnitude of substitutability between petroleum and electricity provides a result of significant interest and is consistent with findings in the literature including Smyth et al. [25] on Chinese iron and steel sector. This implies that Liberia has the potential to switch from GHG emitting petroleum to cleaner energy sources; hence, retaining the ability to fuel its industrial economy, while reducing the adverse environmental implications. Indeed, meeting this potential can limit Liberia's vulnerability to international oil shocks and reduce balance of payment problems since in fact the country is well short of oil resources and relies heavily on the importation of petroleum products to satisfy bulk of its energy needs. Notwithstanding, it has to be pointed out that

Table 2
Correlation analysis[a].

Variable	Capital	Labor	Petroleum	Electricity
Capital	–			
Labor	−0.2425 (0.189)	–		
Petroleum	0.9074 (0.000)	−0.3592 (0.047)	–	
Electricity	0.8528 (0.000)	−0.4210 (0.018)	0.9156 (0.000)	–

[a] Values in parentheses indicate p-values.

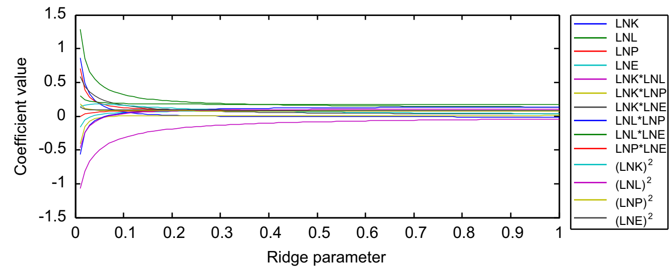

Fig. 3. Ridge trace plot of the coefficient estimates of the ridge regression.

Table 3
Ridge regression estimates.

Variable	Coefficient	Probability value
LNK	0.0129	0.054
LNL	0.2235	0.013
LNP	0.0985	0.090
LNE	0.0698	0.095
LNK × LNL	−0.0698	0.068
LNK × LNP	0.0094	0.072
LNK × LNE	0.0418	0.100
LNL × LNP	0.1274	0.054
LNL × LNE	0.1727	0.082
LNP × LNE	0.0815	0.071
$(LNK)^2$	0.0558	0.066
$(LNL)^2$	0.1011	0.019
$(LNP)^2$	0.0775	0.036
$(LNE)^2$	0.0870	0.263
Constant	6.2327	0.077
Ridge k	0.6	
Coefficient of determination	0.9186	
F-statistics	72.820	0.001

[6] Since this technique is popular in the literature, its mathematical details are not presented here to conserve space. Interested readers are however referred to Soper et al. [33]; Kendall and Stuart [34]; etc.

[7] The value 0.6 was supported by the variance inflation factor (VIF), an index that measures how much the variance (the square of the estimate's standard deviation) of an estimated regression coefficient is increased because of collinearity.

[8] A possible explanation for the difference is that Wesseh and Zoumara [1] used aggregate energy consumption and the model did not consider capital stock.

[9] This could be a bit confusing since Wesseh and Zoumara [1] attributed the up-ward trend in employment level during the civil war to high migration of the labor force in search of refuge and not the level of economic activities.

Table 4
Output elasticity of alternative inputs in the Liberian economy[a].

Year	η_{Kt}	η_{Lt}	η_{Pt}	η_{Et}
1980	0.0483	1.0587	0.4619	0.2953
1981	0.0482	1.0592	0.4605	0.2946
1982	0.0483	1.0626	0.4613	0.2952
1983	0.0483	1.0654	0.4618	0.2955
1984	0.0481	1.0633	0.4594	0.2938
1985	0.0482	1.0654	0.4599	0.2945
1986	0.0479	1.0608	0.4552	0.2933
1987	0.0475	1.0538	0.4493	0.2912
1988	0.0478	1.0586	0.4541	0.2930
1989	0.0470	1.0482	0.4476	0.2898
1990	0.0454	1.0171	0.4299	0.2762
1991	0.0445	1.0019	0.4184	0.2712
1992	0.0445	1.0008	0.4184	0.2713
1993	0.0445	1.0005	0.4187	0.2715
1994	0.0447	1.0030	0.4205	0.2722
1995	0.0448	1.0059	0.4212	0.2727
1996	0.0448	1.0101	0.4223	0.2732
1997	0.0451	1.0187	0.4247	0.2749
1998	0.0456	1.0283	0.4276	0.2769
1999	0.0458	1.0351	0.4294	0.2782
2000	0.0461	1.0418	0.4318	0.2795
2001	0.0459	1.0439	0.4325	0.2798
2002	0.0462	1.0487	0.4348	0.2809
2003	0.0459	1.0479	0.4344	0.2801
2004	0.0462	1.0526	0.4361	0.2814
2005	0.0465	1.0580	0.4379	0.2827
2006	0.0469	1.0654	0.4419	0.2848
2007	0.0472	1.0723	0.4449	0.2862
2008	0.0472	1.0752	0.4438	0.2862
2009	0.0474	1.0801	0.4439	0.2870
2010	0.0477	1.0861	0.4452	0.2880
Average	**0.0465**	**1.0448**	**0.4397**	**0.2836**

[a] All values have been rounded-off to four decimal places.

Table 5
Substitution elasticity of alternative inputs in the Liberian economy[a].

Year	σ_{KL}	σ_{KP}	σ_{KE}	σ_{LP}	σ_{LE}	σ_{PE}
1980	1.0006	1.0006	1.0004	1.0004	1.0024	1.0045
1981	1.0006	1.0006	1.0004	1.0005	1.0025	1.0045
1982	1.0006	1.0006	1.0004	1.0006	1.0025	1.0045
1983	1.0006	1.0006	1.0004	1.0006	1.0026	1.0045
1984	1.0006	1.0006	1.0004	1.0007	1.0026	1.0045
1985	1.0006	1.0006	1.0004	1.0008	1.0026	1.0045
1986	1.0006	1.0006	1.0004	1.0010	1.0026	1.0043
1987	1.0006	1.0006	1.0004	1.0012	1.0027	1.0041
1988	1.0006	1.0006	1.0004	1.0010	1.0026	1.0042
1989	1.0006	1.0006	1.0005	1.0012	1.0027	1.0041
1990	1.0007	1.0006	1.0004	1.0016	1.0032	1.0046
1991	1.0007	1.0006	1.0004	1.0021	1.0033	1.0044
1992	1.0007	1.0006	1.0004	1.0020	1.0033	1.0044
1993	1.0007	1.0006	1.0004	1.0020	1.0032	1.0044
1994	1.0007	1.0006	1.0004	1.0019	1.0032	1.0044
1995	1.0007	1.0006	1.0004	1.0020	1.0032	1.0044
1996	1.0007	1.0006	1.0004	1.0020	1.0033	1.0044
1997	1.0007	1.0006	1.0004	1.0021	1.0033	1.0044
1998	1.0007	1.0006	1.0004	1.0022	1.0033	1.0043
1999	1.0007	1.0006	1.0004	1.0023	1.0033	1.0043
2000	1.0007	1.0006	1.0004	1.0023	1.0034	1.0043
2001	1.0007	1.0006	1.0004	1.0023	1.0034	1.0043
2002	1.0007	1.0006	1.0004	1.0023	1.0034	1.0043
2003	1.0007	1.0006	1.0004	1.0023	1.0034	1.0044
2004	1.0007	1.0006	1.0004	1.0023	1.0034	1.0044
2005	1.0007	1.0006	1.0004	1.0023	1.0034	1.0043
2006	1.0007	1.0006	1.0004	1.0022	1.0034	1.0044
2007	1.0007	1.0006	1.0004	1.0022	1.0034	1.0044
2008	1.0007	1.0006	1.0004	1.0024	1.0034	1.0043
2009	1.0007	1.0006	1.0004	1.0025	1.0034	1.0042
2010	1.0007	1.0006	1.0004	1.0026	1.0035	1.0042
Average	**1.0007**	**1.0006**	**1.0004**	**1.0017**	**1.0031**	**1.004**

[a] All values have been rounded-off to four decimal places.

opportunities to substitute electricity for petroleum in Liberia are limited in practice because of the serious damages to electricity infrastructures caused by fourteen years of civil war in the country. Turning to substitutability between energy and capital, the empirical literature has reached mixed conclusions on this point. While some studies have found capital and energy to be complements (e.g. Fuss [36], Berndt and Wood [37], Magnus [38]), others have found capital and energy to be substitutes (e.g. Griffin and Gregory [39]; Pindyck [4]). In this study, we find that the substitution elasticity between capital and energy is about one over the sample period and is consistent with findings in the literature (e.g. Smyth et al. [23] on Chinese iron and steel sector; Cho et al. [40] on South Korea; Christopolous and Tsionas [41] on Greece; Vega-Cervera and Medina [42] on Portugal). This result suggests that removal of price ceilings on energy in Liberia would tend to reduce energy use and increase capital intensiveness. The types of substitution possibilities here could involve, for example, manual operation, semi-mechanical and some production processes (Smyth et al. [23]; Ma et al. [17]). Shifting focus to substitutability between energy and labor, one can notice the slight increase over time. In fact, the substitution elasticity between energy and labor is higher than that between capital and energy. Even though one may argue that the difference is relatively small and can be neglected in research practice, this result reflects the fact that there are more incentives for labor investment than capital inputs. Observing from Fig. 2, this should not be surprising since over the majority of the period studied there has been rising labor investment and relatively lower capital in Liberia.

An attempt has also been made to obtain the relative differences in technical progress of all input pairs considered in this study. This was done by making use of the aggregate translog production function of the Liberian economy and combining the output elasticities and estimated coefficients from Eq. (4). The specific function used for the calculation can be given as follows:

$$RD_{ij} = (\alpha_i/\eta_i) - (\alpha_j/\eta_j) \quad (19)$$

In the above equation, RD_{ij} represents the difference between technical progress of inputs i and j α_i and α_j are estimated coefficients from Eq. (4) while η_i and η_j indicate the output state of technical knowledge. Positivity of RD_{ij} is a direct indication that the state of technical progress for input i is faster than that of input j. Negativity of RD_{ij} however means that the state of technical progress for input j is faster than that of input i. Better still, if RD_{ij} is zero, this implies equality in technical progress for both inputs. The result of this analysis is presented in Fig. 4. As can be seen, there are some differences in the relative technological progress of the four inputs, but the differences are generally small and there seems to be not much evidence of convergence over time. The difference in technical progress between capital and other resources is positive and there is not much decline over time. On the other hand, the difference in relative technological progress between labor and energy and between petroleum and electricity is negative with no increase over time, consistent with no convergence in relative technological progress. These results seem to suggest that even though the state of technical progress for electricity is faster than petroleum and capital faster than labor, petroleum will continue to play a dominant role in the energy consumption mix of Liberian industry while labor investment will continue to outweigh capital inputs.

6. Conclusion and policy suggestion

6.1. Conclusion

This study has attempted to investigate technical change, inter-factor and inter-fuel elasticity of substitution between capital,

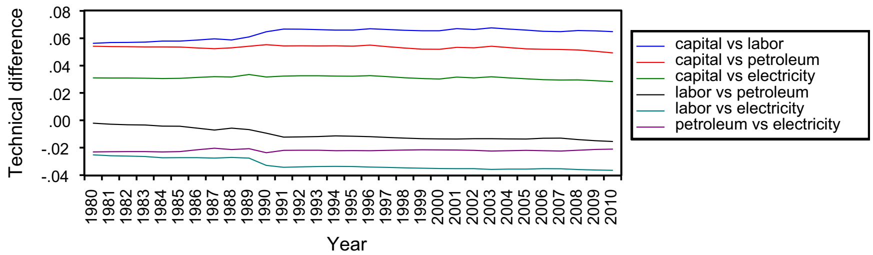

Fig. 4. Difference in technical progress among different inputs.

labor, petroleum and electricity in Liberia by employing a log linear translog production and cost function. The ridge regression estimation technique has been used due to evidence of multi-collinearity in the data. The empirical applications to yearly classical factor and energy inputs over the period 1980 to 2009 document several findings. First, there is clear evidence that output of the Liberian economy is positively and significantly linked to capital, labor, petroleum and electricity. This finding provides insights that energy serves as catalyst for growth of the Liberian economy and hence contributes to the literature on energy consumption–growth nexus. Second, we show that electricity is a substitute for petroleum in Liberia's industrial production. This implies that Liberia has the potential to switch from GHG emitting petroleum to cleaner energy source like electricity; hence, retaining the ability to fuel its industrial economy, while reducing the adverse environmental implications. Meeting this potential can limit Liberia's vulnerability to international oil shocks and reduce balance of payment problems since in fact the country is well short of oil resources and relies heavily on the importation of petroleum products to satisfy bulk of its energy needs. Notwithstanding, opportunities to substitute electricity for petroleum in Liberia are limited in practice because of the serious damages to electricity infrastructures caused by 14 years of civil war in the country. Third, the study demonstrates strong potential for substitution between capital and energy suggesting that removal of price ceilings on energy in Liberia would tend to reduce energy use and increase capital intensiveness. In addition, the study unravels relatively higher potential for substitution between labor and energy than between capital and energy reflecting the fact that there are more incentives for labor investment than capital inputs. Finally, our results seem to provide evidence that petroleum will continue to play a dominant role in the energy consumption mix of Liberian industry while labor investment will continue to outweigh capital inputs. In summary, forecasting models for future factor demand and energy demand in Liberia can make use of the inter-factor and inter-fuel elasticities of substitution obtained in this study.

6.2. *Policy suggestion*

The results of this study provide significant policy implications for Liberia especially in the context of the global clamor for carbon emission reduction. In line with the international community's efforts toward climate change mitigation and the principles of extending energy access to all Liberians through careful consideration of the environmental costs and benefits, and with the goal of maximizing efficiency to minimize costs and any adverse environmental impacts, the government of Liberia will have to properly determine its future energy policies. It is obvious that the issue of low carbon would be the bedrock for these policies. In fact, in its National Energy Policy (NEP), the Liberian government has made the following ambitious commitments using 2009 as the base year: (i) reduce GHG emissions by 10% by the energy sector in 2015; (ii) improve energy efficiency by 20% by 2015; (iii) raise the share of renewable energy from current level of 10% to 30% of electricity production in 2015; (iv) increase the level of biofuels in transport fuels to 5% by 2015; (v) implement a long-term strategy to make Liberia a carbon neutral country, and eventually less carbon dependent by 2050 (Wesseh and Zoumara [1]). Indeed, the industrial economy will be fundamental to turning this vision into reality. Change, however, cannot come at the cost of growth, and Liberia will need to take a delicate balancing act as the country moves towards a slower pace of development based on upgraded value chains and energy-efficient business. Success in our view will depend on the ability of firms in the economy to cope with the government's goals.

First, since all inputs were found to be substitutes, policies intended to promote increased use of alternative sources of energy can present opportunities. With electricity being substitutable with petroleum for instance, the Liberian government can encourage firms in the economy to use more electricity and lesser petroleum through taxes, subsidies, or more competitive electricity pricing. However, the extent to which substituting electricity for petroleum will be effective in reducing GHG emissions depends on the extent to which petroleum is used to generate electricity. Hence, it is necessary also to underscore the importance of the Liberian government policies that focus on increasing the installed capacity of renewable electricity generation within the context of substitutability between petroleum and electricity. In addition, the fact that there are substantial substitution possibilities not only between capital and energy, but also energy and labor is promising and highlights the need for capital and labor-friendly policies.

Second, policies aimed at stimulating growth of the electricity market should be prioritized. The government will need to embark on electricity infrastructure projects and ensure that the share of electricity in the economy fuel mix is increased and that the transmission mechanism is improved.

Third, since a switch from one factor or energy source to another would require a certain level of change in technology, this could bring about higher capital expenditures on new machines, engine upgrades, or new production equipment, etc., when trying to accommodate the change in factor or energy usage. Given the costs associated with such change, price-based or regulatory policies alone may not be fully effective. Therefore, it might be necessary for the government to implement strategies intended to minimize capital expenditures related to factor or energy switching. For instance, capital subsidies, lower taxes on capital expenditures, etc., should also be implemented in line with price-based policies.

Finally, some studies have pointed out (e.g. Zhang and Wang [43]; Smyth et al. [25]) that larger enterprises may have significant level of efficiency advantages over their smaller counterparts. This provides insights that the ability of enterprises to substitute electricity for petroleum and the resulting productivity effect thereof will to a larger extent depend on their sizes, thus providing support for merger policies. Hence, the merger control agency of Liberia will have to develop consistent methods of implementing merger control rules.

At this junction, we hasten to remark that despite the contribution of this study, there are also some limitations that should be pointed out. First, the ridge regression technique adopted in this study in order to solve the problem of multi-collinearity and loss in efficiency due the sheer number of parameters should not be treated without a second thought since the model had to incorporate some degree of bias. This also forced the authors to lump energy inputs into groupings so as to lessen the number of parameters to be estimated. Finally, considering the electricity mix and computing the elasticity between each form of electricity production would have been a nice thing to do but the unavailability of relevant data limits the scope and methodology used in this study. However, this is often beyond the ability and control of the researcher. Much more data are necessary to perform a well-supported calculation. The accuracy and reliability of the data used also affects the accuracy and application of the analyses performed in this study. Hence, resolving the above limitations appears to be a viable avenue for further research and model improvement.

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